CONVERSION FACTORS, ACRONYMS, and ABBREVIATIONS

Multiply	*By*	*To obtain*
centimeter (cm)	0.3937	inch
meter (m)	3.281	foot
kilogram (kg)	2.2046	pound

Degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows: °F = 1.8 x (°C + 32)

FAO	Food and Agriculture Organization of the United Nations
FFWCC	Florida Fish and Wildlife Conservation Commission
U.S.	United States
USGS	U.S. Geological Survey
ppm	part per million
S$	Singapore currency
$	United States currency

Unless otherwise stated in this report, measurement of fish refers to **total length**, defined as the measurement made from the tip of the snout to the posterior tip of the caudal or tail fin. **Standard length** refers to the measurement made from the tip of the snout to the base of the caudal fin.

SNAKEHEADS (Pisces, Channidae)— A Biological Synopsis and Risk Assessment

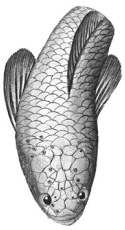
By Walter R. Courtenay, Jr., and James D. Williams

ABSTRACT

Snakeheads (family Channidae) are airbreathing freshwater fishes containing two genera, *Channa* with 26 species native to Asia, Malaysia, and Indonesia; and *Parachanna* with 3 species native to tropical Africa. Some snakeheads are small, reaching about 17 centimeters, but most are much larger, the largest reported to be 1.8 meters in length. All are considered thrust predators with most being piscivorous as adults.

A few of the smaller snakeheads and colorful juveniles of some larger ones have been available to hobbyists through the aquarium fish trade. Several species are highly valued as food fishes within parts of their native ranges, especially in Asia where they are an important part of capture fisheries and aquaculture.

Because of these uses by humans, introductions far beyond native ranges have occurred. One Asian snakehead has been established in Oahu, Hawaii, since before 1900. Another species was discovered established in southeastern Florida in 2000, and a third in a pond in Maryland in 2002. Others have been captured from natural waters of the United States without evidence of reproduction and likely represent released aquarium fishes. That snakeheads at or near sexual maturity were being sold alive in ethnic food markets raised fears that they could be introduced into novel waters. These concerns led to this study on the biology of snakeheads. A risk assessment is included that examines environmental and related aspects of snakehead introductions.



INTRODUCTION

Snakeheads (family Channidae) are airbreathing freshwater fishes containing two genera, *Channa,* native to Asia, Malaysia, and Indonesia, and *Parachanna*, endemic to tropical Africa. Taxonomy of these fishes is in flux, but leading authorities on snakehead systematics currently recognize 26 species of *Channa* and 3 of *Parachanna*. A few snakeheads are small, reaching about 17 centimeters; most, however, are much larger, the largest reported to be 1.8 meters in length. All are considered thrust predators with most being piscivorous as adults.

Within parts of their native ranges, some species of snakeheads are highly valued as food fishes, particularly in India, southeastern Asia, China, and to a lesser extent in Africa. They have long been an important part of capture fisheries and, in recent decades, some species have been utilized in aquaculture and a few used as predators to control density of tilapiine fishes in culture.

Because of its popularity as a food fish in southern China and adjacent southeastern Asia, the chevron snakehead (*Channa striata*) has been reported as widely introduced into islands from the western Indian Ocean eastward to Hawaii. The northern snakehead (*C. argus*) has been a market leader, and is cultured in China and Korea. This species has been exported to other nations, including Canada and the United States where it has been sold alive in certain ethnic markets and restaurants. Although purposefully introduced and established in Japan in the early 1900s, its introduction and subsequent establishment in ponds, rivers, and reservoirs of Kazakhstan, Turkmenistan, and Uzbekistan (formerly part of the Soviet Union) in the early 1960s appear to have been accidental.

Other snakeheads utilized as food fishes include the Chinese snakehead (*Channa asiatica*), blotched snakehead (*C. maculata*), and spotted snakehead (*C. punctata*). The bullseye snakehead (*C. marulius*), found in the live-food and aquarium fish trades, is now established in Broward County, Florida, and the blotched snakehead has been established in Oahu, Hawaii, prior to 1900.

Snakeheads used in the aquarium fish trade include a few small species and brightly colored juveniles of several large snakeheads. They are moderately popular with hobbyists in Japan and Europe. Several species are marketed in Canada and have been sold in the U.S., even in states where possession of live snakeheads has been illegal for decades. Hobbyists and importers can purchase snakeheads through a variety of sites on the Internet. Because of their highly predacious nature, however, snakeheads have not had a large following of interested hobbyists in the U.S. Those who purchased attractively colored juveniles of the larger species typically found that snakeheads became incompatible with other fishes (even killing others of their own kind), required expensive food (preferably live), and quickly outgrew their aquaria. This apparently has led to releases of “pet” snakeheads. As a result of these habits and their prohibition in several states, snakeheads have had a limited market in the U.S. aquarium fish trade. The fact remains, however, that they have been available for purchase.

The earliest known record of snakehead imports into the contiguous U.S. was published by Brind (1914). The importation consisted of about 60 juvenile fish that we believe were blotched snakeheads. Their progeny are thought to have been consumed by parent fish (Brind, 1914). Klee (1987) noted that a snakehead species, the chevron snakehead, probably a misidentification of the Chinese snakehead, was in the U.S. aquarium fish trade by 1912. Ross B. Socolof (personal commun., 2003) said that the Chinese snakehead was the first snakehead imported for the U.S. aquarium fish trade in the very late 1800s or early 1900s. Innes (1917) mentioned snakeheads as aquarium fishes, but did not include individual species. Innes (1920) reported on his having received a "breeding pair" of what he cited as *Channa fasciata* from a colleague who brought the fish to him from San Francisco. He indicated that a "single adult pair and a few young" of this snakehead had been "recently imported into California from Southern Asia." The photograph of this fish in Innes (1920) is clearly that of the Chinese snakehead, and the same photograph appeared in the account of the Chinese snakehead by Innes (1955). Armstrong (1923) purchased four progeny of Inne's snakehead in 1922, and included his failures and success in breeding these fish and their care under aquarium conditions. Stoye (1935) and Axelrod and Schultz (1955) provided descriptions, illustrations, and information on the care and breeding of Chinese snakehead, leading us to believe that it was available for sale to aquarium hobbyists through at least the 1950s.

The Chinese snakehead is one of a few species known to crawl short distances overland—references to this snakehead in the aquarium fish literature may have played a role in creation of an information "strip" on this species, published by Walt Disney Productions in 1959 (fig. 1), and brought to our attention by Robert Howells of the Texas Department of Parks and Wildlife.

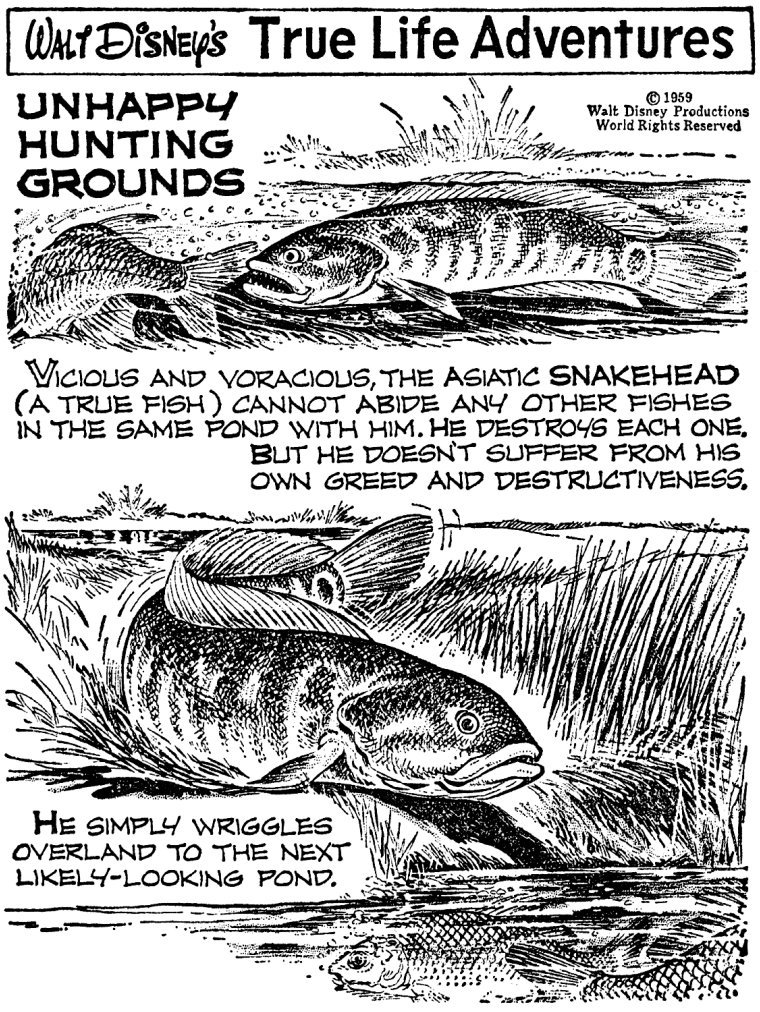


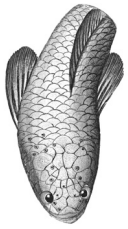
Figure 1—Perhaps due to its availability in the aquarium fish hobby through the 1950s, Walt Disney Productions published this depiction of the Chinese snakehead, *Channa asiatica*, in 1959. This is a species of snakehead known to crawl overland for short distances. Reprinted with permission of Disney Publishing Worldwide.

A comprehensive snakehead fish study, including a biological synopsis, risk assessment, and accounts for each species, was conducted between September 2001 and September 2002 by the U.S. Geological Survey, with support provided by the Division of Scientific Authority and Fisheries Management of the U.S. Fish and Wildlife Service. This study was prompted for several reasons—

- The discovery of an established population of *Channa marulius* in Broward County, Florida, in 2000;
- A well established snakehead (*C. maculata*) population in Oahu, Hawaii, since the late 1800s;
- Recent captures of introduced snakeheads in several states; and
- Recognition that channid fishes (at or near sexual maturity) were being sold in live-food fish markets in the U.S.

A limited number of snakeheads have been available for sale through the aquarium fish trade for several decades, but a new pathway— introduction of these fishes in live-food fish markets—had been largely overlooked.

Because snakeheads are highly predatory, some having the ability to travel overland to new water bodies, the inevitable release of these fishes by hobbyists, escapes from aquaculture, and liberation of live-food fish into U.S. waters threatens aquatic ecosystems. This report provides a comprehensive assessment of the risks involved with introductions of potentially invasive snakeheads into non-native waters.



LITERATURE REVIEW AND BACKGROUND INFORMATION

TAXONOMY AND SYNONYMY

According to Nelson (1994), the group of teleostean fishes known as snakeheads is classified as follows:

- *Class* Actinopterygii
  - *Subclass* Neopterygii
    - *Order* Perciformes
      - *Suborder* Channoidei
        - *Family* Channidae

Two genera are currently recognized as comprising the family Channidae. They are *Channa* (Scopoli, 1777; snakeheads of Asia, Malaysia, and Indonesia) and *Parachanna* (Teugels and Daget, 1984; African snakeheads). Generic synonyms of *Channa* include *Channa* Gronow, 1763, a *nomen nudum*; *Ophicephalus* Bloch, 1793, and its misspelled version *Ophiocephalus*; *Bostrychoides* Lacepède, 1801; and *Philypnoides* Bleeker, 1849. Synonyms of *Parachanna* are *Ophiocephalus* Günther, 1861; *Parophiocephalus* Senna, 1924 (originally proposed as a subgenus, but preoccupied in the fish family Anabantidae by *Parophiocephalus* Popta, 1905); and *Channa* Scopoli, 1777. Synonyms of the 29 species of snakeheads described herein are included in the individual species accounts contained in the section “Species Accounts.”

Myers and Shapovalov (1932) reviewed the status of the genera *Ophicephalus* and *Channa*, and they concluded that the practice of separating the two based on presence (*Ophicephalus*) or absence (*Channa*) of pelvic fins was invalid, based on specimens of *C. gachua* from India and one from Taiwan (introduced) that lacked pelvic fins. They placed *Ophicephalus* as a junior synonym of *Channa*. Five species of *Channa* lack pelvic fins.

Vierke (1991b), Musikasinthorn (2000), Musikasinthorn and Taki (2001), and Zhang and others (2002) consider 29 species of this family as valid (table 1). Nevertheless, 87 species and 4 subspecies have been described (Eschmeyer, 1998, in part) and current taxonomy is in flux. Although many described species are now considered synonyms of recognized species, there are about 20 names that cannot be associated with valid taxa. The plethora of scientific names for snakeheads is in part due to the sometimes dramatic color changes that occur between early and late juvenile stages, and adult patterns, a factor then unknown and hence unrecognized by early taxonomists using color as one of the distinguishing characteristics. Moreover, some descriptions lack detail, illustrations, or type specimens that could assist in solving these taxonomic mysteries. Four new species have been described since 1990, another put into synonymy, and two removed from synonymy and recognized as valid during that same time period. A taxonomic revision of the family is being prepared (Prachya Musikasinthorn, personal commun., 2002) and will likely result in more species being recognized as valid, and new species will perhaps be described.

Table 1—Currently recognized species of the family Channidae

[After Vierke (1991b), Musikasinthorn (2000), Musikasinthorn and Taki (2001), and Zhang and others (2002). Bibliographic sources are cited in the References section of this report or in Eschmeyer (1998)]

Channa amphibeus (McClelland, 1845) - Chel snakehead[1]
Channa argus (Cantor, 1842) - northern snakehead[1]
Channa asiatica (Linnaeus, 1758) - Chinese snakehead
Channa aurantimaculata Musikasinthorn, 2000 - orangespotted snakehead [1]
Channa bankanensis (Bleeker, 1852) - Bangka snakehead[1]
Channa baramensis (Steindachner, 1901) - Baram snakehead[1]
Channa barca (Hamilton, 1822) - barca snakehead
Channa bleheri Vierke, 1991 - rainbow snakehead
Channa burmanica Chaudhuri, 1919 – Burmese snakehead[1]
Channa cyanospilos (Bleeker, 1853) - bluespotted snakehead[1]
Channa gachua (Hamilton, 1822) - dwarf snakehead[3]
Channa harcourtbutleri (Annandale, 1918) - Inle snakehead[1]
Channa lucius (Cuvier, 1831) - splendid snakehead
Channa maculata (Lacepède, 1802) - blotched snakehead[1]
Channa marulius (Hamilton, 1822) - bullseye snakehead [1,3]
Channa marulioides (Bleeker, 1851) - emperor snakehead
Channa melanoptera (Bleeker, 1855) - blackfinned snakehead[1]
Channa melasoma (Bleeker, 1851) - black snakehead
Channa micropeltes (Cuvier, 1831) - giant snakehead[3]
Channa nox Zhang, Musikasinthorn, and Watanabe, 2002 – night snakehead[1]
Channa orientalis Schneider, 1801 - Ceylon snakehead[2]
Channa panaw Musikasinthorn, 1998 - panaw snakehead[1]
Channa pleurophthalma (Bleeker, 1851) - ocellated snakehead[1]
Channa punctata (Bloch, 1793) - spotted snakehead[3]
Channa stewartii (Playfair, 1867) - golden snakehead
Channa striata (Bloch, 1797) - chevron snakehead[3]
Parachanna africana (Steindachner, 1879) - Niger snakehead[1]
Parachanna insignis (Sauvage, 1884) - Congo snakehead[1]
Parachanna obscura (Günther, 1861) - African snakehead

[1] Proposed common name. [2] Common name tentative. [3] Species complex.

COMMON NAMES

As is typical of fishes of foreign origin, there has been a history of different English common names utilized for snakeheads. It is not unusual to find dissimilar names used for juveniles and adults of the same species, particularly in the aquarium fish trade. Moreover, one can find several English common names in the scientific literature for the same species in different parts of its native range. This also is true for common names used by indigenous people for the same species. In India, for example, various common names for a single species are often used by people from diverse regions, states, or cultures. For purposes of this report, we have followed Robins and others (1991) in using common names for the two snakeheads they treated, selected names we felt appropriate primarily from those used in the aquarium fish trade, and have added proposed names for some species that lacked English common names (table 1). The common names are identified in table 1 and appear in bold type in the section "Species Accounts."

Accounts for each of these species are detailed in the section "Species Accounts," which includes illustrations or photographs, source of original description, type specimens, synonyms, common name(s), native range, introduced range, size, habitat preference, temperature range, reproductive habits, feeding habits, characters, commercial importance in the United States, commercial importance in native range, and environmental concerns. Where known, the diploid chromosome number is included. Each account also contains a map showing native range and, where known, location or range of introductions. Literature citations for some synonyms are not included in the "References" section but can be found in Eschmeyer (1998) or on the Internet at http://www.calacademy.org/research/ichthyology/catalog/fishcatsearch.html.

DESCRIPTION AND DISTINGUISHING CHARACTERISTICS

Fishes of the family Channidae are commonly referred to as snakeheads (sometimes serpent-heads), primarily because of their somewhat elongated and cylindrical bodies, but particularly due to the presence of large scales on the head of most species, reminiscent of the large epidermal scales (cephalic plates) on the heads of snakes. Another snake-like feature is the somewhat flattened head with eyes located in a dorsolateral position on the anterior part of the head. Anterior nostrils are present and tubular. Dorsal and anal fins are elongated, and all fins are supported only by rays. A few species lack pelvic fins (Nelson, 1994; Berra, 2001). The caudal fin is rounded. The mouth is terminal and large with a protruding lower jaw, which is toothed, often containing canine-like teeth. The prevomer and palatines may or may not be toothed, depending on species. Scales are cycloid or ctenoid. All species possess paired suprabranchial chambers located behind and above the gills. The chambers in *Channa* are bordered by two plates, one from the epibranchial of the first gill arch and the other as an expansion of the hyomandibular. Those in *Parachanna* have a simple cavity not involving processes from the first epibranchial or hyomandibular. These chambers are not labyrinthic (Berg, 1947), but are lined with respiratory epithelium. All species occupy freshwater and a few can tolerate extremely low salinities.

Illustrations or photographs of certain species of *Channa* appear in Nichols (1943), Munro (1955), Nakamura (1963), Mohsin and Ambak (1983), Masuda and others (1984), Lim and Ng (1990), Ng and Lim (1990), Lee and Ng (1991, 1994), Pethiyagoda (1991), Talwar and Jhingran (1992), Kottelat and others (1993), Jayaram (1999), and Kottelat (1998, 2001a). The three species of *Parachanna* were illustrated by Bonou and Teugels (1985), who provided a key for identification of *Parachanna*. But, there is no single key to identify all species of *Channa*, at least five of which appear to be species complexes rather than single, distinct species.

Two larger snakehead species, the bullseye snakehead (*Channa marulius*) and emperor snakehead (*C. marulioides*), superficially resemble the native bowfin (*Amia calva*) in that all three are elongated fishes, have long dorsal fins, tubular nostrils, and an ocellus near the base of the upper part of the caudal fin. The bowfin, however, has its pelvic fins in an abdominal rather than thoracic or anterior-abdominal position, and the anal fin is not elongated. Moreover, the bowfin lacks a rosette of enlarged scales on top of its head. Other than this example, there are no native fishes in North America or within their native ranges with which snakeheads could be confused.

Native Distribution

Species and species complexes of the genus *Channa* are native from southeastern Iran and eastern Afghanistan eastward through Pakistan, India, southern Nepal, Bangladesh, Myanmar, Thailand, Laos, Malaysia, Sumatra, Indonesia, Vietnam, Korea, and China northward into Siberia (fig. 2).

Of the currently recognized 26 species of *Channa*, 8 species and representatives of 4 species complexes occur in peninsular Malaysia, Sumatra, and/or Indonesia. Of the same 26 species, 13 species and 1 species complex are tropical to subtropical; members of 6 species and 2 species complexes are warm temperate to subtropical/tropical, 2 species complexes are cold temperate to subtropical/tropical, and 1 species is warm temperate to boreal and can live beneath ice in the northern part of its range. The three species of *Parachanna* are native to Africa and are tropical (fig. 2).

Snakeheads are non-ostariophysan primary freshwater fishes (Mirza, 1975, 1995) and have little or no tolerance for seawater. Habitat preferences vary by species or species complex, with a majority occurring in streams and rivers. Others live in swamps, rice paddies, ponds, and ditches. All can tolerate hypoxic conditions because they are airbreathers from late juvenile stages. The pH range, where known, varies by species with one, the Bangka snakehead (*Channa bankanensis*), preferring highly acidic (pH 2.8-3.8) waters (Lee and Ng, 1991; Ng and Lim, 1991). At least three species are tolerant of a wide pH range: the dwarf snakehead (*C. gachua*), spotted snakehead (*C. punctata*), and chevron snakehead (*C. striata*) survived for 72 hours at pH levels ranging from 4.25 to 9.4 (Varma, 1979).

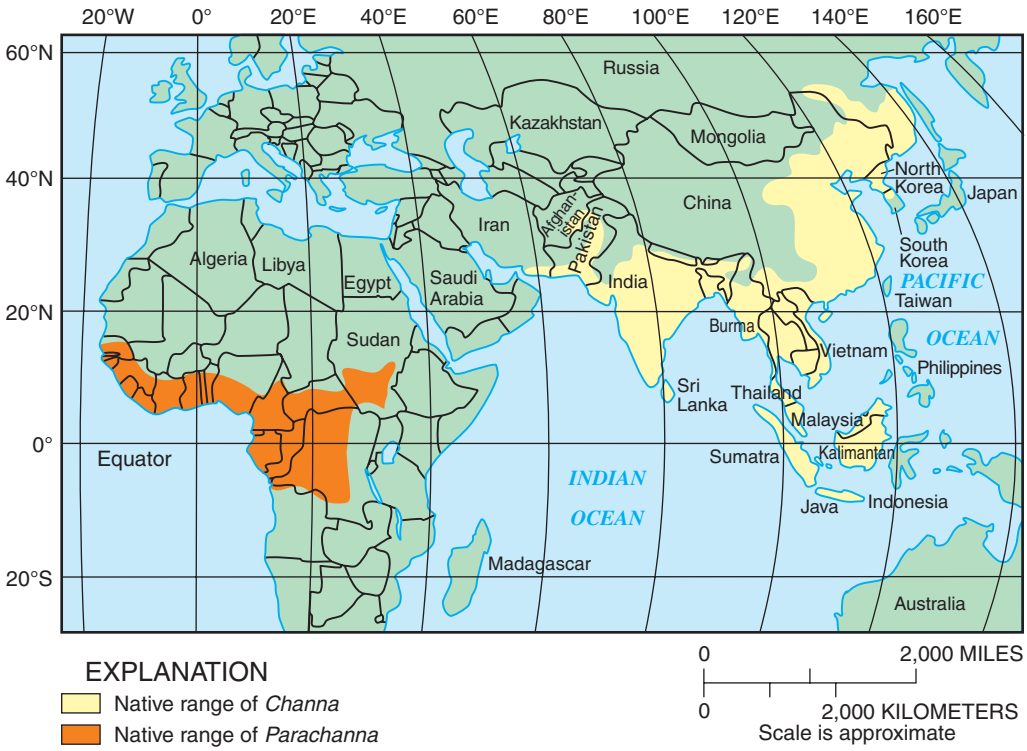


Figure 2—Native distribution of the family Channidae.

Biology and Natural History

• ***Paleogeographic origins***—The fossil record indicates the presence of channid fishes during the upper Oligocene/lower Miocene in what is now western Switzerland and eastern France (Reichenbacher and Weidmann, 1992). Nevertheless, Ralf Britz (personal commun., 2003) noted that identification of these fishes is based on fossilized otoliths and may not be reliable.

Lydekker (1886) reported on fossilized skull bones of snakeheads from the Siwalik Hills, Himachal Pradesh, northern India. These fossils and additional material of Pontian age (early Pliocene) were described in more detail by Sahni and Khare (1977) who described *Channa bhimachari*, *C. gregoryi*, and *C. romeri* based on fossilized skull-bone material found in stream sediments. Comparing these skeletal elements to osteological preparations of recent snakeheads, they suggested that *C. bhimachari* was most closely related to *C. striata* and *C. gregoryi* to *C. marulius*. They were unable to determine a recent relative of *C. romeri*.

Boeseman (1949) described skull-bone fossils of a snakehead from Pleistocene deposits from Trinil, central Java. Based on comparisons with osteological preparations of recent snakeheads, he concluded that these fossilized remains were of a species closely related to living *Channa striata*, and he named the species *Ophicephalus palaeostriatus*. Coupled with data presented by Lydekker (1886), Boeseman (1949), and Sahni and Khare (1977), there is convincing evidence that congeners of living snakeheads were present in Asia by and probably well before the Pleistocene.

A majority of living snakeheads are native to southeastern Asia, with most species found from Myanmar eastward and southeastward through Malaysia, Sumatra, Java, and Borneo (Kalimantan). Boeseman (1949) confirmed that at least one species of what is now included in the genus *Channa* was present in Java in the Pleistocene. Jocano (1975) noted that during the Pleistocene, the Malay Peninsula, Sumatra, Borneo, and the "Sundas" to Palawan were connected by what is termed the "Sunda Shelf." He described conditions as "a vast dryland covering 1.8 million square kilometers," containing a "great river," adding that many of the present river systems of Kalimantan, Sumatra, and surrounding localities were tributaries of that river. He also added that this "may explain the striking similarities of fish faunas in Sumatra, Borneo, and the Philippines," the latter restricted to the Palawan region of the Philippines.

From an evolutionary standpoint and considering a Pliocene to Pleistocene presence of channid fishes in Asia, it is likely that the "great river" of the Sunda Shelf began to dry during the late Pleistocene and speciation of snakeheads in the region was in advanced stages. This probably occurred before parts of that shelf became isolated as peninsulas and islands, with species evolving in differing kinds of habitats separated from their ancestral origin(s) by geographic and biological factors. Such an evolutionary scenario explains why, for example, species known from Sumatra also occur in the southern part of the Malay Peninsula and Kalimantan, Bangka, Billiton, perhaps Bali, and nearby areas. Moreover, isolation of such species "populations" between continental and insular ranges over geologic time has doubtless led to genetic and phenotypic differences that complicate taxonomic interpretations. Similar linkages between what are now continental areas and nearby islands (for example, Vietnam and China with Hainan) are known from the Pleistocene (Sterling and others, 2003). India and Sri Lanka are reported to have been connected as recently as 8,000 years ago (www.tamilinfo.org).

Fossils of snakeheads have also been identified from post-Pleistocene deposits in the Sahara Desert (Van Neer, 1989). Banerjee and others (1988) suggested an origin of the family from the area of Yunnan Province, southern China, dating back to the Pliocene or earlier, but based their suggestion on ecological habitats currently occupied by snakeheads rather than from fossil evidence. A more accurate picture of where this family evolved and its ancestor(s) is yet to be determined.

- ***Spawning seasons and reproductive behavior—***There is a paucity of information on reproductive biology of many species, but several conclusions can be drawn for those that are known. Spawning seasons vary by species. Spawning in several species occurs primarily in summer months (June through August) but, in at least two (the *Channa striata* and *C. punctata* species complexes), breeding pairs can be found throughout the year. Some species spawn twice to three or more times each year. Okada (1960) reported that female northern snakehead are capable of spawning five times per year. There are several reports that when snakeheads pair, they remain monogamous for a spawning season, perhaps longer, but this may not apply across the life history of any individual snakehead.

Most snakeheads build nests by clearing a generally circular area in aquatic vegetation, often weaving the removed vegetation around the centrally cleared area. This results in a vertical column of water surrounded by vegetation. Sometimes the

surface of this column contains pieces of removed vegetation. One species complex (*Channa punctata*) prepares elaborate tunnels through vegetation leading into the nest column. In general, the male entwines his body around that of the female, with some species appearing to "dance" in the water column as eggs are released and fertilized (Breder and Rosen, 1966; Ng and Lim, 1990). Eggs are buoyant, due to a large oil droplet in the yolk mass, and rise to the surface where they are vigorously guarded by one or both parents. Some snakeheads in one species complex (*C. gachua*) and *C. orientalis* are reported to be mouthbrooders, with the male being the mouthbrooder of fertilized eggs and, later, fry in *C. orientalis*. Peter Ng (personal commun., 2002) suggested that *C. asiatica* may also be a mouthbrooder. Most snakeheads, however, are not mouthbrooders and one or both parents vigorously guard their young. One species (*C. micropeltes*) is reported to have attacked and, in some instances killed, humans who approached the mass of young (Kottelat and others, 1993). Thus, parental care, whether by guarding or mouthbrooding, is a behavioral characteristic of snakeheads.

One might assume, based on reported spawning habits, that presence of vegetation is mandatory for successful spawning, but this is not the case. Wee (1982) cited Parameswaran and Murugesan (1976b) as having documented *Channa gachua, C. marulius,* and *C. punctata* spawning in ponds lacking vegetation. Alikunhi (1953) noted that *C. striata* is also known to spawn in the absence of vegetation. These observations, however, imply that other snakeheads are also capable of reproducing in waters lacking vegetation.

- ***Fecundity and early development—***There is limited information on fecundity except for snakeheads of commercial importance. Nevertheless, that information shows a pattern that likely applies to the entire family Channidae. An unfertilized "egg" is an oöcyte. Once an oöcyte is fertilized by fusion of oöcyte and sperm nuclei, it becomes an egg, with an embryo resulting if fertilization is successful. Smaller snakeheads, such as *Channa gachua* and *C. orientalis*, produce few oöcytes (about 20 when sexual maturity is first reached and up to 200 later; Lee and Ng, 1991, 1994). Low fecundity is a general rule among mouthbrooding fishes (Breder and Rosen, 1966). Fecundity increases greatly in larger snakeheads and appears to be linear, increasing in volume with increasing body length. For example, Quayyum and Qasim (1962) recorded fecundity ranging from 2,300-26,000 oöcytes for *C. striata*, increasing in number with increasing body length. Large female bullseye snakeheads, *C. marulius*, among the largest species, have been reported to produce as many as 40,000 oöcytes (Jhingran, 1984). A fecundity for the northern snakehead, *C. argus*, was about 50,000 oöcytes (Frank, 1970). Frank's data came from Nikol'skiy (1956), who recorded fecundity of 22,000-51,000 in northern snakeheads from the Amur basin. Dukravets and Machulin (1978) gave fecundity rates of 28,600 to a high of 115,000 for northern snakehead (probably from Yangtze River stock) introduced into the Syr Dar'ya basin of Turkmenistan/Uzbekistan. They also noted that, whereas growth of northern snakeheads is slower than that reported for this species from the Amur basin, growth rates from both stocks became equal once sexual maturity was reached.

Oöcytes, when released from the female parent, are small, ranging from about 1 mm to slightly over 2 mm in diameter, depending on species. Fertilization takes place by the male releasing milt (sperm) on the oöcytes as they emerge from the female. Development time to hatching varies with water temperature and, to a lesser extent, with the species involved. For example, hatching occurred in 54 hours at 16-26 ºC and 30 hours at 28-33 ºC in *Channa punctata* (Kahn, 1924). In the northern snakehead, *C. argus,* eggs hatch in 28 hours at 31 ºC, 45 hours at 25 ºC, and 120 hours at 18 ºC. In general, newly hatched fry, depending on species, are about 3.0-3.5 mm in length.

• ***Early life history—***Following yolk resorption, snakehead fry begin feeding on zooplankton. Fry typically remain together until they reach early juvenile stage, guarded by one or both adults, when they can fend for themselves (Lee and Ng, 1994). Late juveniles of the giant snakehead, *Channa micropeltes*, school and feed in packs (Lee and Ng, 1991). Although there are few reports of early life history except for species of commercial importance, it appears that as larval snakeheads mature to early juvenile stages, the diet changes to small crustaceans and insects, particularly insect larvae. Presence of phytoplankton, plant material, and detritus in the digestive system of young snakeheads, as well as adults, appears to occur from incidental ingestion. Juveniles frequently differ in colors and color patterns from late juveniles to adults, making young of interest to some aquarium hobbyists (Lee and Ng, 1991, 1994).

• ***Respiration and overland migrations—***Snakeheads are highly evolved airbreathing teleostean fishes, and several are capable of overland migration by wriggling motions (Lee and Ng, 1991; Berra, 2001; Peter Ng, personal commun., 2002) despite the fact their pectoral fins lack spines like those of clariid catfishes. They possess suprabranchial chambers for aerial respiration, and the ventral aorta is divided into two parts to permit bimodal (aquatic and aerial) respiration (Das and Saxena, 1956; Graham, 1997). The suprabranchial chambers become functional during the juvenile stage of growth (Graham, 1997), following which some species of snakeheads are obligate and others are facultative airbreathers. In some large species of snakeheads, such as *Channa marulius*, the young are facultative airbreathers and adults are obligate breathers (Wee, 1982), but all species are airbreathers.

These suprabranchial chambers lie above the pharynx and gill arches, lateral to the otic chambers of the skull. In *Channa*, the chambers open into the pharynx through inhalant apertures. The chamber lining contains respiratory “islets” with vascular papillae. The chambers can be filled with air or water. In addition, in *C. striata*, there are also vascular papillae in the epithelium of the mouth and pharynx that can be utilized for respiration; these, however, can be retracted into depressions in the epithelium to prevent damage when feeding (Munshi and Hughes, 1992).

Some channids, perhaps all, have a circadian rhythm in frequency of oxygen uptake. *Channa marulius*, for example, showed a peak in oxygen uptake at night. *Channa striata* and *C. gachua* peaked in early night hours, and *C. punctata* at dusk. These rhythms are attributed to evolution in swamp ecosystems (that is, the rhythm is a property of the ecosystem) (Munshi and Hughes, 1992).

The number of species of snakeheads capable of overland migrations is unknown, but several display such behavior (Khin, 1948). These migrations often are assumed to be the result of fish relocating from drying habitats in search of those with water, perhaps driven by instinctive behavior for better feeding conditions, or both.

Overland migrations likely apply to those species whose native range is subject to seasonal dry/wet (or monsoonal) conditions, which encompass much of western to southeastern Asia where the majority of snakehead species exist.

The species of *Channa* most capable of overland migrations are those that are somewhat flattened ventrally (Peter Ng, personal commun., 2002). These include *C. asiatica*, *C. gachua*, *C. micropeltes*, *C. melasoma*, *C. nox*, *C. orientalis*, and *C. striata*. Even large *C. micropeltes* are capable of "crawling" in a sinuous motion on dry or wet land, although movement is slow (Peter Ng., personal commun., 2002). Those snakeheads with more rounded bodies (for example, *C. argus*, *C. lucius*, and *C. maculata*) have very limited ability to move on land except as young, and only when some water is present, as under mild flooded conditions. Liem (1987) noted that *Channa*, like airbreathing catfishes (*Clarias* and *Heteropneustes*), do not migrate on land to escape drying habitats, but burrow into mud to survive droughts. These species only migrate during or soon after heavy rains, allowing these fishes to invade new habitats, which permits a wider dispersal from more crowded environments (Liem, 1987).

- ***Hypoxic survival—***Snakeheads are either obligate or facultative airbreathers. Therefore, survival in hypoxic waters is not problematic to these fishes. When prevented from access to the surface, adult snakeheads of many species will drown due to lack of oxygen (Day, 1868; Lee and Ng, 1991). Cold temperatures reduce metabolism as well as oxygen demand, allowing such species as *Channa argus* to survive under ice (Frank, 1970). Moreover, snakeheads can remain out of water for considerable periods of time as long as they remain moist. Some snakeheads, especially *C. striata,* can bury themselves in mud during times of drought (Smith, 1945). They are known to secrete mucus that helps to reduce desiccation and facilitates cutaneous breathing (Mittal and Banerji, 1975; Lee and Ng, 1991). Fishers in Thailand are aware of this habit and, during drought periods, will slice into the mud until they locate the fish (Smith, 1945).

- ***Lifespan—***No specific information appears in literature. One species (*Channa marulius*) is reported to reach a total length of 1.8 m in Maharashtra State, India (Talwar and Jhingran, 1992), a size that would suggest a relatively long lifespan. Nevertheless, we have been unable to find an ichthyologist who knows of preserved specimens of such a length. The typical maximum length stated for *C. marulius*, the largest snakehead, is 1.0-1.2 m. Nina Bogutskaya (personal commun., 2002) stated she had seen a specimen of *C. argus* that was almost 1.5 m in length, also indicating a relatively long-lived species. Moreover, Peter Ng (personal commun., 2003) reported that *C. micropeltes* is known to reach 1.5 m in length. Smaller snakeheads, such as members of the *C. gachua* and *C. orientalis* species complexes, may not live for more than a few years. Most larger snakeheads are reported to reach sexual maturity within 2 years, after which growth slows but fecundity increases with increasing size. The few publications that discussed growth rates in snakeheads based on examination of scales or otoliths were inconclusive as to the interpretation of "growth" markings. Moreover, timeframes of these studies were of such short duration (a few years) that they documented no evidence of maximum lifespan.

● ***Feeding habits*—**Few studies analyze the feeding habits of snakeheads. For those species studied, however, snakehead fry feed mostly on zooplankton following yolk-sac resorption. Munshi and Hughes (1992) cited Banerji (1974) that fry of *Channa punctata* feed on phytoplankton. As juveniles, they feed on insect larvae, small crustaceans, and fry of other fishes (Munshi and Hughes, 1992). What is universal in reports of adult feeding habits is that all snakeheads are predators, with many species showing a preference for other fishes, although they may also consume crustaceans, frogs, smaller reptiles, and sometimes young birds and small mammals. Welcomme (1985) cited *C. lucius, C. micropeltes, C. pleurophthalma* and *C. striata* as "large predators eating fish of all sizes, shrimps, prawns and crabs." Under conditions of food depravation, snakeheads can become cannibalistic on their young. The piscivorous nature of snakeheads has led to the use of some species (*C. striata* and *Parachanna obscura* in particular) to control tilapia fish populations in aquaculture.

School of young giant snakehead, *Channa micropeltes*, feeding at the surface in Thailand. Photo courtesy of Jean-Francois Helias, Fishing Adventures Thailand.

ASSOCIATED DISEASES AND PARASITES

Investigations of diseases and parasites of snakeheads concentrate on those species of importance in aquaculture. Hoffman and Schubert (1984) noted that most fishes can sometimes be hosts of parasites. Snakeheads are no exception.

Jinhui (1991) listed parasitic crustaceans of *Channa argus, C. asiatica,* and *C. punctata* from Chinese waters. A listing of known parasites of *C. gachua, C. marulius, C. punctata,* and *C. striata* from Bangladesh was provided by Arthus and Ahmed (2002). In that study, parasites of all but *C. gachua* equaled or far outnumbered the parasites reported by Bykhovskaya-Pavlovskaya and others (1964) for *C. argus* (table 2).

Literature on parasites of snakeheads includes numerous descriptions of new species, not detailed herein, but indicates that most studies concentrate on cultured fishes, such as *Channa argus, C. punctata, and C. striata*. Chiba and others (1989) noted that *C. argus* and *C. maculata* introduced parasites to Japan, but did not detail the parasites involved or fish species affected. None of the parasite literature we reviewed on snakeheads indicated that any of these represent a potential threat to native North American fishes. Conversely, such potential has not been examined.

A disease of snakeheads that has received broad attention is epizootic ulcerative syndrome (EUS), which causes high mortality in these fishes, particularly *Channa striata* and *C. punctata* under intensive culture. EUS involves several

Table 2—Parasites of northern snakehead (*Channa argus*)

[Adapted from Bykhovskaya-Pavlovskaya and others, 1964]

Parasite	*Group*	*Host tissues*	*Other fishes affected*
Myxidium ophiocephali	Myxosporidia	gallbladder, liver ducts	
Zschokkella ophiocephalli	Myxosporidia	kidney tubules	
Neomyxobolus ophiocephalus	Myxosporidia	gill filaments	
Mysosoma acuta	Myxosporidia	gill filaments	crucian carp
Myxobolus cheisini	Myxosporidia	gill filaments	
Henneguya zschokkei ?	Myxosporidia	gills, subcutaneous, musculature	salmonids (tubercle disease of salmonids)
Henneguya ophiocephali	Myxosporidia	gill arches, supra-branchial chambers	
Henneguya vovki	Myxosporidia	body cavity	
Thelohanellus catlae	Myxosporidia	kidneys	
Gyrodactylus ophiocephali	Monogenoidea	fins	
Polyonchobothrium ophiocephalina	Cestoidea	intestine	
Cysticercus gryporhynchus cheilancristrotus	Cestoidea	gallbladder, intestine	cyprinids, perches
Azygia hwangtsiüi	Trematoda	intestine	
Clinostomum complanatum	Trematoda	body cavity	perches
Pingis sinensis	Nematoda	intestine	
Paracanthocephalus curtus	Acanthocephala	intestine	cyprinids, esocids, sleepers, bagrid catfishes
Paracanthocephalus tenuirostris	Acanthocephala	intestine	
Lamproglena chinensis	Copepoda	gills	

pathogens, including motile aeromonad bacteria (for example, *Aeromonas hydrophila, A. caviae, Pseudomonas fluorescens*; Prasad and others, 1998; Qureshi and others, 1999), a fungus, *Aphanomyces invadans* (considered a primary pathogen; Mohan and others, 1999; Miles and others, 2001), and perhaps a rhabdovirus (Kanchanakhan and others, 1999; Lio-Po and others, 2000). Another bacterium, *Aquaspirillum* sp., also has been implicated (Lio-Po and others, 2000). EUS may have originated in India in the 1980s, but has since been found in Pakistan, Thailand, and the Philippines, with outbreaks reported from all of these areas during the 1990s. Snakeheads are not the only fishes affected by this disease. It is also known to occur in airbreathing catfish (*Clarias*), the bagrid catfish genus *Mystus*, two cyprinid genera (*Cyprinus* and *Puntius*), mastacembelid eels (*Mastacembelus*), and the nandid genus *Nandus* in India (Mukherjee, 1998). In Thailand, it has been found in giant gourami (*Osphronemus goramy*) and climbing perch (*Anabas testudineus*) during an outbreak in 1996-1997 (Kanchanakhan and others, 1999).

A parasitic disease that can affect humans is gnathostomiasis, caused by a helminth parasite, *Gnathostoma spinigerum*. It has been recognized as a highly important disease with about 800 suspected cases per year in two hospitals in Bangkok, Thailand, between 1985 and 1988 (Setasuban, 1990). *Channa striata* has been identified as an intermediate host for this parasite, found mostly in muscle tissue and occurring in 100 percent of fish examined over 41 cm in length (Setasuban and others, 1991). It is unknown if additional species of snakeheads in Thailand and other countries of southeastern Asia may serve as an intermediate host for larvae of this parasite.

HISTORY IN FISHERIES AND AQUACULTURE

Most snakeheads are part of capture fisheries. Few details were found in the literature on fishing methods, but most appear to involve hook and line, traps, gillnets, or seines.

Species for which we have found no information that they are of importance as a fishery resource include *Channa amphibeus, C. bankanensis, C. burmanica, C. cyanospilos,* and *C. melasoma.* Some do not appear to be targets of active fisheries, but are believed or known to be periodically available in local markets as incidental catches. These species include *C. aurantimaculata* (Musikasinthorn, 2000), *C. baramensis* (Ng and others, 1996), *C. barca* (also in the aquarium trade; Talwar and Jhingran, 1992), *C. bleheri* (wild caught for the aquarium trade; Ralf Britz, personal commun., 2002), *C. gachua* (Talwar and Jhingran, 1992), *C. harcourtbutleri* (Ng and others, 1999), perhaps *C. melanopterus, C. nox* (Zhang and others 2002), *C. panaw* (Musikasinthorn, 1998), *C. stewartii* (Talwar and Jhingran, 1992), and possibly *Parachanna africana* and *P. insignis*. Those for which there are active commercial fisheries are *C. argus* (Berg, 1965; Baltz, 1991; Dukravets, 1992), *C. asiatica* (Nichols, 1943; Daiqin and others, 1999), *C. lucius* (for food and aquarium purposes; Ng and Lim, 1990), *C. maculata* (Nichols, 1943; Atkinson, 1977; Hay and Hodgkiss, 1981), *C. marulioides* (aquarium purposes; Ng and Lim, 1990), *C. marulius* (Sriramlu, 1979; Rao and Durve, 1989; Talwar and Jhingran, 1992), *C. micropeltes* (Lee and Ng, 1991; Dudley, 2000), *C. orientalis* (Rainboth, 1996), *C. pleurophthalma* (Lee and Ng, 1991; Kottelat and others, 1993; Dudley, 2000), *C. punctata* (Quayyum and Qasim, 1962; Bhuiyan and Rahman, 1984; Rao and Durve, 1989; also in aquarium trade, Talwar and Jhingran, 1992), *C. stewartii* (minor importance in India, also in aquarium trade; Talwar and Jhingran, 1992), *C. striata* (Roa and Durve, 1989; Talwar and Jhingran, 1992), and *P. obscura* (aquarium and food purposes; Dankwa and others, 1999) . In addition, *C. argus, C. maculata,* and *C. striata* are commercially fished in most areas where these species have been introduced. Interestingly, there are cultural differences in acceptance of using introduced *C. argus* as a food fish. Within its native range in China, Korea, and southern Siberia (Berg, 1965), and within its introduced range in Kazakhstan, Uzbekistan, and Turkemistan, it is considered a desirable and sought-after food fish (Baltz, 1991; Dukravets, 1992; FAO, 1994); nevertheless, it failed to become popular following its introduction to Japan in the early 1900s (Okada, 1960).

Snakeheads known to be cultured are summarized in table 3. The most important and widely cultured species appears to be *Channa striata*. This may apply, however, only within its native range and perhaps where it has been introduced into southern China. It is becoming evident that it has been misidentified in places where this species has been reported as introduced (Madagascar and Hawaii in particular), and the introduced snakehead is *C. maculata* (Ralf Britz, personal commun., 2002). Thus, the many reported introductions of *C. striata* to Pacific Islands summarized by Eldredge (1994) and Lever (1996) will require reexamination. *Channa maculata* is the second most important snakehead cultured in China (Fang Fang, personal commun., 2002), and its culture appears to be concentrated primarily in Guangdong Province, where it is native. During 2001, imports of snakeheads (likely *C. maculata*) into the U.S. increased, the point of export having been Ghangzhou, Guangdong Province. Until identification of introduced "*C. striata*" is verified, its reputation as the most widely cultured snakehead

***Table 3*—**Species of the family Channidae currently known to be cultured for food and/or aquarium fish trade

Channa argus[1]	*Channa maculata*
Channa asiatica	*Channa micropeltes*[2]
Channa marulius	*Channa striata*[3]
Channa punctata	*Parachanna obscura*

[1]Second most important species cultured for food. Also, the only species that has been in culture in the contiguous United States (Arkansas).
[2]Appears to be the most important species cultured for the aquarium fish trade.
[3]Species most widely cultured for food. Being cultured in Hawaii.

remains in question. We have verified that it is in culture in Hawaii (Qin and Fast, 1996a,b,c; Qin and others, 1997; Qin, Fast, and Kai, 1997; Qin, He, and Fast, 1997; Qin and Fast, 1998; Pam Fuller, personal commun., 2002). Moreover, it is considered to be the most important species economically in India (Bhatt, 1970), and is being cultured there and in Thailand, Java (Hofstede and others, 1953); Vietnam (Pantulu, 1976; Bard, 1991); the Philippines (Conlu, 1986; Guerrero, 2000); Sri Lanka (Kilambi, 1986); Pakistan (Talwar and Jhingran, 1992); Malaysia (Ali, 1999); and Cambodia (Balzer and others, 2002).

Channa argus is the most important snakehead cultured in China (Fang Fang, personal commun., 2002) where it is grown in ponds, rice paddies, and reservoirs (Atkinson, 1977; Sifa and Senlin, 1995; Liu and others, 1998). It was being cultured on three fish farms in Arkansas until importation, culture, sale, and possession of snakeheads was prohibited by the Arkansas Fish and Game Commission in August 2002.

Channa micropeltes is cultured for food in Vietnam (Pantulu, 1976; Wee, 1982), Malaysia (Lee and Ng, 1991), Thailand (FAO, 1994), and Cambodia (Rainboth, 1996), and often in floating cages (Pantulu, 1976; Rainboth, 1996). Young of this species are sold in the aquarium fish trade where this species, at least in the U.S., has been the most available snakehead.

Channa marulius is cultured in ponds, ricefields, and irrigation wells that do not support other fishes in Pakistan and India (Bardach and others, 1972). Wee (1982) noted that it is reared in monoculture in India, where it is fed tilapia. Mirza and Bhatti (1993) contradicted Bardach and others (1972) in stating that this species is unsuitable for aquaculture in Pakistan due to its highly piscivorous nature. Young have been available in the aquarium fish trade and are presumed to have originated from cultured stock.

Channa punctata has been an important food fish in India, where it is fished commercially and reared in ponds (Quayyum and Qasim, 1962; Talwar and Jhingran, 1992). Some snakehead species, including *C. punctata,* used in intensive aquaculture, are subject to outbreaks of EUS, and this has been reported for this species in India (Prasad and others, 1998; Qureshi and others, 1999).

Parachanna obscura is being cultured in the Central African Republic (Micha, 1974), Ondo State, Nigeria (Ajana, 1983; Victor and Akpocha, 1992), Benin (Jackson, 1988), and Ghana (Morrice, 1991).

HISTORY OF INTRODUCTIONS

Eastern Hemisphere

Locations where snakeheads have been introduced beyond their native ranges in the Eastern Hemisphere are shown in figure 3.

- *Channa argus*—Reported as introduced into "Czecho-Slovakia" and Russia beginning in 1949 (Holcík, 1991). No specific localities of introduction or information on status of the releases were provided by Holcík (1991). Nina Bogutskaya (personal commun., 2002) reported early introductions that failed into the Volga delta and ponds in Ekaterinburg (formerly Sverdlovsk) Province in the southern Urals. An experimental introduction was made in ponds of Moscow Province during 1949-1950 that established. In 1953, it was recommended that the species be stocked widely, but that failed to happen. There was a report in a Russian aquarium journal in 1963 noting occurrence of this species in small lakes in the Podolsk Region, Moscow Province, but the species is presently absent from the Moscow area. Tandon (1976) reported that acclimatization experiments were conducted in the former Soviet Union after 1950, and that fry were collected from ponds near Moscow and the Ukraine in 1955 and sent to Czechoslovakia for acclimatization purposes. He concluded that the source of the original stock was the Amur basin.

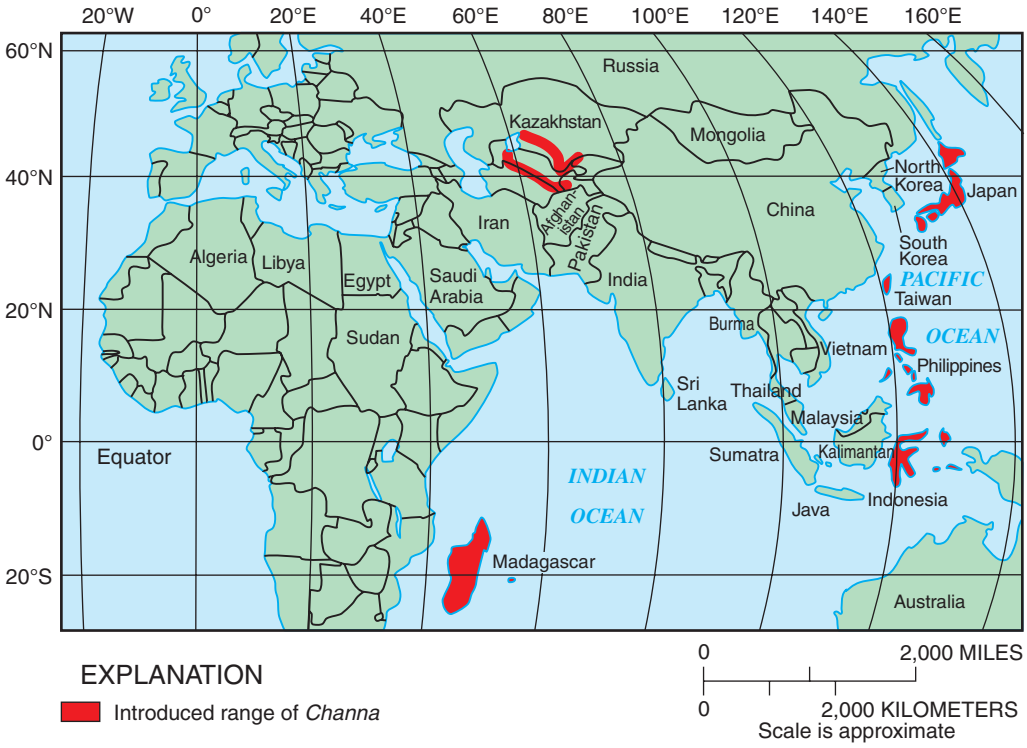


Figure 3—Introductions of snakeheads in the Eastern Hemisphere.

The northern snakehead was introduced into the Aral Sea basin in the early 1960s where it became established in the Amu Dar'ya, Syr Dar'ya, and Kashka-Dar'ya rivers of Kazakhstan, Turkmenistan, and Uzbekistan (Dukravets and Machulin, 1978; Usmanova, 1982; Guseva, 1990; Dukravets, 1992). The initial introduction was apparently accidental, with snakeheads mixed with shipments of Asian carps. All introductions were apparently from Yangtze basin stock (Sal'nikov, 1998), although some authors claim the stock came from the Amur basin and were purposeful releases to establish a food resource. Dukravets (1992) recorded additional introductions that became established in the Sarysu River, reservoirs on the Talus River, and Chu River of Kazakhstan during the 1980s. He also reported that 10 metric tons of northern snakeheads was harvested from reservoirs along the Talus River in 1989.

The northern snakehead was introduced from Korea in the early 1900s and became established in many waters of central and southern Japan (Okada, 1960; Nakamura, 1963; Uyeno and Akai, 1984), which includes the islands of Hokkaido, Honshu, Kyushu, and Shikoku (Hiroshi Ueda, personal commun., 2002).

- ***Channa asiatica*—**Introduced and established in Taiwan (Musikasinthorn, 2000), probably released as a food resource.

- ***Channa gachua*—**Ismail (1989), misidentifying this snakehead as *C. orientalis* (Ralf Britz, personal commun., 2003), included Kalimantan (southern Borneo) in the native range of this species, and Kottelat (1985) noted its presence in the Greater Sunda Islands of Indonesia (probably including Kalimantan). This may represent an introduction, but the rationale for introducing this very small snakehead is not apparent. Myers and Shapovalov (1932) recorded this species in Taiwan.

- ***Channa maculata*—**Introduced and established as a food resource in Taiwan; Nara, Hyôgo, Hiroshima, Mie, and Shiga prefectures, Japan; and the Philippines (Okada, 1960; Liang and others, 1962; Hay and Hodgkiss, 1981; Uyeno and Akai, 1984). Ralf Britz (personal commun., 2002) confirmed that it is this species, not *C. striata*, that is established in Madagascar. He has also identified this species as present in Oahu, Hawaii, since about 1900, based on specimens examined at the U.S. National Museum of Natural History.

- ***Channa melasoma*—**Perhaps introduced and established in Palawan, Philippines (Kottelat, 1985). Pathway and rationale unknown.

- ***Channa micropeltes*—**We believe the presence of the giant snakehead in Kerala State, southwestern India, and described by Day (1865a) as *Ophiocephalus diplogramma* was the result of an introduction from southeastern Asia that occurred prior to the mid-1800s.

- ***Channa punctata*—**Smith (1950) reported this species as introduced in the vicinity of Delagoa Bay, southern Mozambique. Paul Skelton (personal commun., 2001) stated that no snakehead has been found or reported from southern Africa since the Smith (1950) record.

• ***Channa striata*—**This species has been reported as the most widely introduced species of snakehead. It was recorded as introduced and established in Madagascar (Raminosoa, 1987; Reinthal and Stiassny, 1991; Stiassny and Raminosoa, 1994; Lévêque, 1998), although Ralf Britz (personal commun., 2002) stated that this was a misidentification of *C. maculata*. The chevron snakehead is also recorded from the following locations, although some of these records may prove to be *C. maculata*, misidentified as *C. striata*: Mauritius (Parameswaran and Goorah, 1981; Welcomme, 1988, Lever, 1996); Philippines (Seale, 1908; Herre, 1924, 1934; Conlu, 1986); Vogelkop Peninsula, Papua, Indonesia (Allen, 1991); Sundaland, Sulawesi, Lesser Sundas, Moluccas (Welcomme, 1981; Kottellat and others, 1993; Lever, 1996). Kottelat and others (1993) reported introductions into China but gave no specific localities. Its presence in Papua, Indonesia, was confirmed through photographs supplied by Gerald L. Allen (personal commun., 2002). The species was also introduced into Fiji and New Caledonia where establishment is questionable, and its introduction to Guam failed (Maciolek, 1984). *Channa striata* is regarded as a prized food fish in many parts of southeastern Asia, and in some localities its oils are used to heal wounds and prevent scarring. Introductions beyond its native range were primarily to establish a live-food resource.

Western Hemisphere

Five species of snakeheads have been reported from open waters of the United States (California, Florida, Hawaii, Maine, Maryland, Massachusetts, North Carolina, Rhode Island, and Wisconsin), and three became established as reproducing populations (fig. 4). One species was being cultured in Arksansas until possession of live snakeheads was prohibited in August 2002 and a fifth species is under culture in Hawaii.

• *California* •

A northern snakehead, *Channa argus*, was collected by California Department of Fish and Game personnel by electrofishing in a reservoir, Silverwood Lake, October 22, 1997. This represents the earliest known record of a live snakehead captured from open waters of the western United States. Silverwood Lake is in the Mohave River drainage, east-northeast of Los Angeles and north of San Bernardino in the San Bernardino Mountains, and receives water from the California Aqueduct. The specimen was subsequently frozen and, apparently, later discarded (Camm Swift, personal commun., 2002). A photograph of the 71 cm specimen that weighed 3.4 kg was taken, which allowed identification of the fish (John Sunada, personal commun. to Camm Swift, 2002). It remains unknown if the snakehead was released into Silverwood Lake or arrived through the California Aqueduct. The aqueduct has been the source of other fishes in the reservoir, including inland silverside (*Menidia beryllina*), striped bass (*Morone saxatilis*), bigscale logperch (*Percina macrolepida*), and tule perch (*Hysterocarpus traskii*) (Swift and others, 1993; Camm Swift, personal commun., 2002).

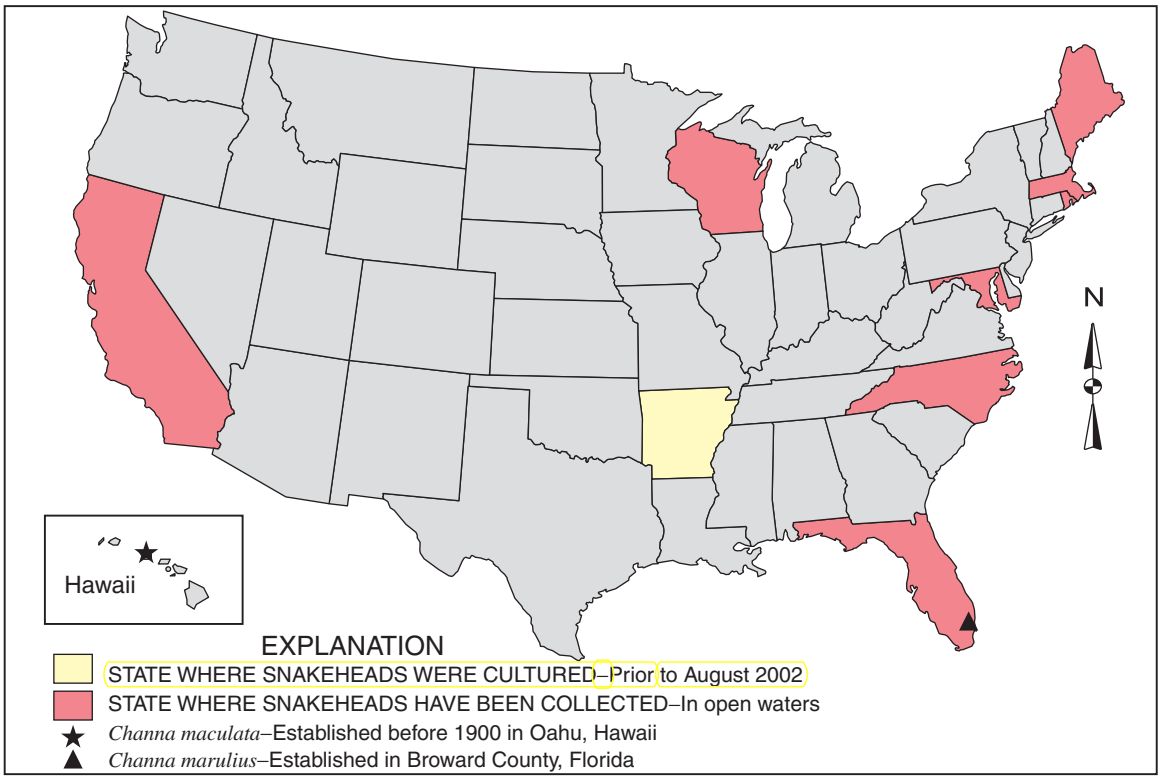


Figure 4—States where snakeheads have been collected from open waters, were cultured prior to August 2002, or are established.

• *Florida* •

An established population of the bullseye snakehead, *Channa marulius*, was discovered in residential lakes and adjoining canals in Tamarac, Broward County, Florida, in 2000 (Florida Fish and Wildlife Conservation Commission, 2001). It is unknown how long this species has occupied these waters, perhaps several years, but both juveniles and adults have been collected, indicating reproductive success. This species is a large snakehead with adults commonly reaching lengths of 120-122 cm (Talwar and Jhingran, 1992). In Maharashtra State, India, it can reach a length of 1.8 m and a weight of 30 kg, and was observed to reach a length of 30 cm in 1 year (Talwar and Jhingran, 1992).

The pathway for the introduction in Broward County, Florida, is unknown. The species may have been purposefully introduced to establish a food or aquarium fish resource or could have been released accidentally by aquarists, in which case several must have been released almost simultaneously. Because this species is considered as a game fish in its native range (http://www.fishingasia.com), it also could have been released illegally to establish a new sport fishing resource. Tamarac is located just east of Water Conservation Area II, north of Everglades National Park, and interconnected canal systems lead into this area. It is likely that *Channa marulius* will expand its range in peninsular Florida as its native range includes tropical to temperate climates. The bullseye snakehead is considered predacious (Jhingran, 1984; Talwar and Jhingran, 1992), especially on other fishes (Schmidt, 2001).

The northern snakehead, *Channa argus*, is also reported from Florida waters. Two individuals were caught in the St. Johns River below Lake Harney, Seminole and Volusia Counties in 2000, with unconfirmed reports of an additional three individuals caught nearby. An attempt to collect additional specimens by Florida Fish and Wildlife Conservation Commission (FFWCC) and U.S. Geological Survey (USGS) personnel by electroshocking in 2001 was unsuccessful, but will be repeated. Until reproduction has been confirmed, we consider the species as present but not established. This fish is not involved in the aquarium fish trade but has been sold in ethnic food markets as a food fish. The most likely pathway is introduction of live-food fish, perhaps to establish a local source.

A live northern snakehead was purchased in a live-food fish market in Orlando, Florida, in March 2002, another indication of its availability in a state where possession is illegal. Moreover, we found a few U.S. aquarium fish retailers that sell snakeheads via the Internet. Three species were purchased from a reputable dealer in Rhode Island who requested a copy of our permit to possess certain restricted fishes, including snakeheads. Private purchases can also be made through several Internet "chat rooms" where possession of permits is doubtlessly of no concern.

• *Hawaii* •

The blotched snakehead (*Channa maculata*), misidentified as the chevron snakehead (*C. striata*), has been established on Oahu, Hawaii, since the late 1800s, possibly introduced from southern China (Herre, 1924). For whatever reasons, it does not appear to have been introduced into other waters of Hawaii, although Morita (1981) reported the species from Kauai. It is now mainly confined to one or more reservoirs on Oahu (Maciolek, 1984). Ralf Britz (personal commun., 2002) has examined two specimens at the U.S. National Museum of Natural History, labeled as *C. striata* that were collected about 1900, and confirmed that they are *C. maculata.* We have examined other specimens, collected in the early 1900s on Oahu, borrowed from the American Museum of Natural History in New York City, Bernice P. Bishop Museum in Honolulu, the California Academy of Sciences in San Francisco, and the Field Museum of Natural History in Chicago, and they, too, are *C. maculata*. Two photographs, reported to be of *C. striata* in Yamamoto and Tagawa (2000) from Hawaii, are that of *C. maculata*. It was those photographs that alerted us to the likelihood that *C. maculata* existed in Hawaii. We believe that all past published records of *C. striata* in Hawaiian waters were based on misidentifications of *C. maculata*.

Channa striata is now being cultured as a food fish on Oahu, first imported in the early 1990s under permit to Arlo Fast of the University of Hawaii (Domingo Cravalho, Jr., personal commun. 2002). Peter Ng (personal commun., 2002) reported that he saw *C. striata* in a market in Honolulu in recent years. Pam Fuller (USGS, Gainesville, Florida) purchased five chevron snakeheads in Honolulu in September 2002. This species is regarded as carnivorous with a preference for other fishes (Mohsin and Ambak, 1983; Conlu, 1986), and was described as a "territorial ambush feeder" (Lee and Ng, 1991). Chevron snakeheads are used to control tilapia populations in culture ponds in the Philippines (Conlu, 1986; Milstein and Prein, 1993), and is one of the species of snakeheads capable of overland migration (Peter Ng., personal commun., 2002).

• *Maryland* •

A northern snakehead, *Channa argus*, was caught by an angler in a 1.8-ha pond in Maryland on May 18, 2002 (Beth Rogers, personal commun., 2002). The angler, unable to identify the fish, took three photographs of the specimen before releasing it into the pond. Estimated total length of the specimen was 43-45 cm. On June 30, 2002, another angler captured a larger (66-67 cm) specimen from the same pond and dipnetted eight juveniles from the pond on the evenings of July 7-8. Maryland Department of Natural Resources personnel subsequently captured over 100 juveniles from the pond, proving that a well established population was present. When the pond was treated with rotenone (a pesticide used for fish management, as well as other uses) in August 2002, more than 1,200 northern snakeheads were recovered (Bob Lunsford and Steve Early, personal commun., 2002). In addition, at least three specimens of the giant snakehead, *C. micropeltes*, have been caught in Maryland waters in recent years (Bob Lunsford, personal commun., 2002). Presence of this subtropical/tropical species in Maryland waters where it could not overwinter likely resulted from releases by aquarists.

Maryland DNR fishery biologist Bob Lunsford examines a berm of sandbags and silt fences strategically placed to prevent pond water overflow or overland fish migration from Crofton Pond to the Little Patuxent River. Photo by Walter R. Courtenay, Jr., USGS.

Biologists dipnetting for snakeheads. Photo by Tom Darden, Governor's office, Annapolis, Maryland.

• *New England States* •

A specimen of the northern snakehead, *Channa argus*, was collected in October 2001 from Newton Pond, Sudbury, Worcester County, Massachusetts, by Massachusetts Department of Fish and Wildlife personnel (Hartel and others, 2002). The likely source is live-food fish markets, as this species was the most common snakehead available in ethnic food markets and restaurants as a live-food fish. Moreover, it is capable of establishment in most freshwaters of the United States. Okada (1960) reported adults as voracious feeders, particularly on other fishes.

Specimens of the giant snakehead, *Channa micropeltes*, have been collected from open waters in Maine, Massachusetts, and Rhode Island (Courtenay and others, 1984; Fuller and others, 1999). This tropical/subtropical species could not establish itself in those temperate waters (Hartel and others, 2002). Juveniles of the species are cardinal red with two dark stripes on either side of the body, and are sold by aquarium fish retailers as red or redline snakeheads. Aquarist-oriented websites note that this species requires much animal food and that growth is rapid. These sites often advise that once these fish reach about 15-20 cm in length, no more than one individual should be kept in a single aquarium because they are aggressive predators. The pathway for release into these New England States was likely aquarists when their "pets" grew too large for their aquaria and/or because of the costs of feeding them. Releases of this species into sub-tropical waters in southern Florida or Hawaii could lead to establishment of this snakehead, regarded as the most predacious channid and known to have attacked humans (Ng and Lim, 1990; Lee and Ng, 1991; Kottelat and others, 1993).

Example of a poster alerting the public about the invasive, non-native snakehead (this poster courtesy of the Maryland Department of Natural Resources).

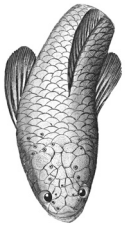
An angler reported having caught two blotched snakeheads, *Channa maculata*, from a bridge over the Charles River in Boston in late July 2002 (Karsten Hartel, personal commun., 2002). We confirmed that two live snakeheads purchased in an ethnic market in Boston in October 2001 by Karsten Hartel were *C. maculata*, thus proving local availability of this species at that time.

• *North Carolina* •

On July 31, 2002, two anglers reported catching two northern snakeheads from Lake Wylie, a reservoir on the Catawba River, Mecklenburg County, North Carolina (Wayne Starnes, personal commun., 2002). North Carolina Wildlife Resources Commission biologists sampled the lake using electrofishing equipment on August 14, 2002, but failed to find any snakeheads (Russell Wong, personal commun., 2002).

• *Wisconsin* •

A single specimen of the giant snakehead, *Channa micropeltes*, was captured by personnel of the Wisconsin Department of Natural Resources in the Rock River near Beloit on September 4, 2003 (Karl J. Scheidegger, personal commun., 2003). This species would not overwinter in Wisconsin and was undoubtedly released by an aquarist.



USES

AQUARIUM TRADE

Aquarists in Japan, Europe, and, to a lesser extent, North America have kept snakeheads as pet fish. Because these fishes are predators (some growing quite large) and high costs are involved with providing preferred live food, few hobbyists become dedicated snakehead enthusiasts. Judging from questions asked in 2002 on various Internet chat rooms dealing with aquarium fishes in general and predatory species in particular, interest in snakeheads seemed to be concentrated among a small number of serious collectors and a slightly larger group of amateur aquarists curious about keeping predators as pets. Most questions appeared to originate from persons who had experience with cichlid fishes, were curious as to whether snakeheads could coexist with other fishes (particularly cichlids), and wanted to know how to maintain snakeheads, what to feed them, what species could be purchased, and where they could be bought. Experienced hobbyists typically cautioned that large aquaria are needed for several available species, that larger snakeheads were intolerant of other fishes and typically another of their own species, and warned of the expenses of providing live food.

Snakeheads that have been periodically available to hobbyists in the U.S. are listed in table 4. This information was assembled in 2002 from various Internet sites in the U.S. and Canada that represent retailers and hobbyist groups and should not be considered a complete "shopping list." Moreover, availability of snakehead species from retailers has been often sporadic. For example, two retailers located in states where importation and possession of snakeheads is legal and who advertise on the Internet rarely have them in stock for sale. A visit to one of these dealers in June 2002 found no snakeheads. A salesperson said they only have them available periodically, adding that among the most popular are "red" snakeheads (a "trade name" for juvenile *Channa micropeltes*, a species that can reach a length of 1 m as an adult and is a voracious predator). Snakeheads have been only a minor part of the aquarium fish trade in the U.S. (Marshall Myers, personal commun., 2002).

Retail aquarium store, Nashville, Tennessee. Photo by Walter R. Courtenay, Jr., USGS.

Table 4—Snakeheads of interest to aquarists in the U.S.

[Information assembled from several aquarist-oriented and retailer websites in 2002. Common names are those often used in the aquarium fish trade]

Channa asiatica	Chinese snakehead
Channa bleheri	Rainbow snakehead, tiger snakehead, python snakehead
Channa marulius	Cobra snakehead
Channa micropeltes	Red snakehead, redline snakehead
Channa punctata	Spotted snakehead
Channa stewartii	Golden snakehead
Parachanna africana	African snakehead

Nevertheless, hobbyists, wholesalers, and retailers have been able to import snakeheads from many exporters in India and southeastern Asia that advertise on the Internet. Individual hobbyists occasionally advertised snakeheads for sale, whereas others inquired about availability on Internet aquarium fish "classifieds" and chat rooms; sometimes these ads or inquiries originated in states where possession of snakeheads is illegal.

Ng and Lim (1990) noted that smaller, colorful snakeheads are important in the aquarium fish trade in southeastern Asia. For example, they mentioned that *Channa gachua* was selling for S$30-60 per individual, and that slightly larger species such as *C. melanoptera* and *C. pleurophthalma* from Borneo, Sumatra, and Malaysia can garner prices as high as S$100 per fish. These fishes are caught wild, are primarily found in forest streams, and with deforestation occurring at a rapid pace, there is fear of overexploitation (Ng and Lim, 1990). In the U.S., prices for *C. bleheri* have ranged from $55-75 per individual for sizes of 8-15.5 cm specimens. Larger species of snakeheads can cost well over $100 per fish, depending on size, with young individuals of the same species fetching prices of $15 or more. Therefore, with their predatory nature, periodic availability, and relatively high prices for purchase and maintenance, snakeheads cannot be considered an important staple of the U.S. aquarium fish industry.

Because 14 states prohibited importation and possession of live snakeheads prior to the Federal ban on importation and interstate transport, the potential aquarium market for these fishes would appear to be limited. Nevertheless, there have been violations of these prohibitions in several states (see section "Regulations as of July 2002").

Larger snakeheads can outgrow their aquaria and/or the interest of their owner(s). Some have been released, as witnessed by the capture of *Channa micropeltes* from the wild in waters of Maine, Maryland, Massachusetts, and Rhode Island (see section "Literature Review and Background Information, History of Introduction, Western Hemisphere"). Fortunately, this subtropical species cannot overwinter in these states.

LIVE-FOOD FISH TRADE

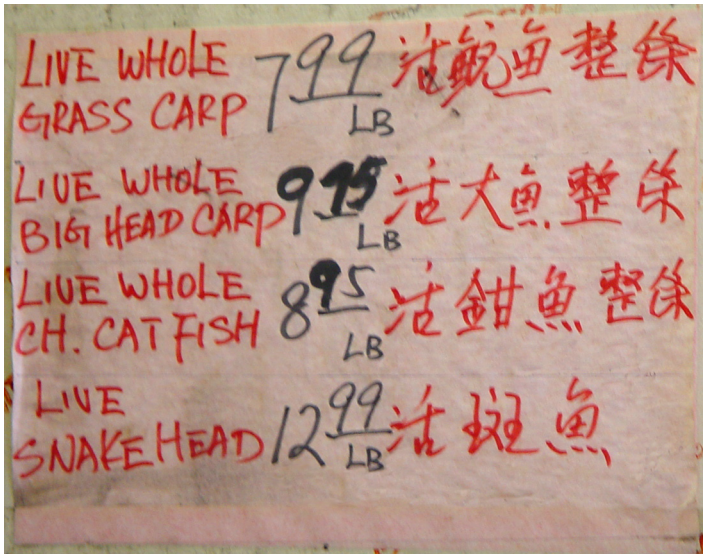
Snakeheads have long been favored food fishes in India and many parts of Asia, particularly southeastern Asia (Lee and Ng, 1991). Some are utilized as luxury specialty foods, available alive in aquaria for customer selection at upscale restaurants in larger cities such as Calcutta, Bangkok, Singapore, Hong Kong, and other major locales. They also provide easily caught food for poorer people (Wee, 1982). These fishes are typically freshly killed, often cooked whole or prepared as filets or steaks, fried or steamed, or included in soups. Excess catches in Thailand and Cambodia are often dried for storage and future use (Wee, 1982; Balzer and others, 2002).

Lee and Ng (1991) noted that snakeheads can remain alive out of water for long periods of time if kept moist. They added that some people believed that this ability may have provided these fishes with healing properties, making them prized as food, particularly to people with illnesses or recovering from surgery. In such situations, the fish are killed just before cooking, the thinking being that healing properties are lost if the fish are killed sooner. They also mentioned that some people in Myanmar believed that one species of snakehead represented humans transformed into fish because of their sins, and that eating one would result in the consumer becoming a lion. Day (1875) noted that some people in India believed that snakeheads that suddenly appeared from mud in the bottom of dried ponds after monsoonal rains actually fell from the sky with the rains.

To illustrate the value of snakeheads in the Orient, Wee (1982) recorded 1977 market prices as $2.50/kg in Taiwan and $1.00/kg in Hong Kong. Ng and Lim (1990) reported prices of S$10 to S$20/kg for live *Channa lucius*, *C. micropeltes*, and *C. striata*, three of the larger snakeheads, in markets in Singapore in the late 1980s.

Asian food market in Nashville, Tennessee, showing tubs and aquaria containing live-food fishes, June 2002. Photo by Walter R. Courtenay, Jr., USGS.

They commented that even smaller species (such as *C. gachua* and *C. melasoma*) are utilized as food in some parts of Asia (such as Myanmar and Sri Lanka), adding that *C. gachua* is sometimes used as bait to catch larger snakeheads. Peter Ng (personal commun., 2003) commented that *C. gachua* was sold alive in May 2000 in fish markets and restaurants in Xishuangbanna and Luxi, Yunnan Province, China, for about S$5/kg, and served in restaurants as whole fish soup. He also noted that *C. marulioides* was sold fresh and dry salted in Sambas and Sintang markets, western Kalimantan, in April 1998. He also saw *C. marulioides* being sold alive in November 1999 in Samarinda, east Kalimantan, and, in 2002, freshly sliced fillets of *C. micropeltes* were sold at S$20/kg in Singapore. In cities such as Hong Kong and Singapore, snakeheads are imported for food from Malaysia and Indonesia. This appears to have led to declines and scarcities of such species as *C. striata* in Malaysia where this fish is considered the most valuable and important snakehead in the nation as food and for medicinal purposes (Wan Ahmad, personal commun., 2001).



Fish market sign at an Asian food market in Honolulu, Hawaii, showing snakehead availability. Photo by Pam L. Fuller, USGS.

As noted earlier, some snakeheads, particularly *Channa striata*, called "haruan" in Malaysia, are important for medical use, particularly in Malaysia and Indonesia. Ng and Lim (1990) and Lee and Ng (1991) noted that *C. lucius* and *C. micropeltes* are also utilized for such purposes in both nations. Mention was made of use in a postnatal diet and during recuperation from illnesses or surgery (Lee and Ng, 1991). Although no specific information was given as to how the fishes were used following surgery, a neighbor of one of the authors (WRC), a Malaysian by birth, stated that the oils from the haruan are used to greatly reduce scarring following surgery, adding she had seen the results and scar tissue was dramatically reduced to a minimum. It has been demonstrated that haruan tissues contain substantial levels of arachidonic acid, a precursor of prostaglandin, essential amino acids (especially glycine), and polyunsaturated fatty acids required to promote prostaglandin synthesis, important factors in wound healing (Baie and Sheikh, 2000).

Channa striata is an important food fish throughout its native range (a species complex distributed from Pakistan eastward to southern China including Malaysia, Indonesia, and Java). Its supposed medicinal value doubtlessly explains why this species is often said to be the most widely introduced species of snakehead as persons of Asian origin emigrated to other locations. *Channa maculata*, often misidentified as *C. striata*, have been imported and released in a similar manner.